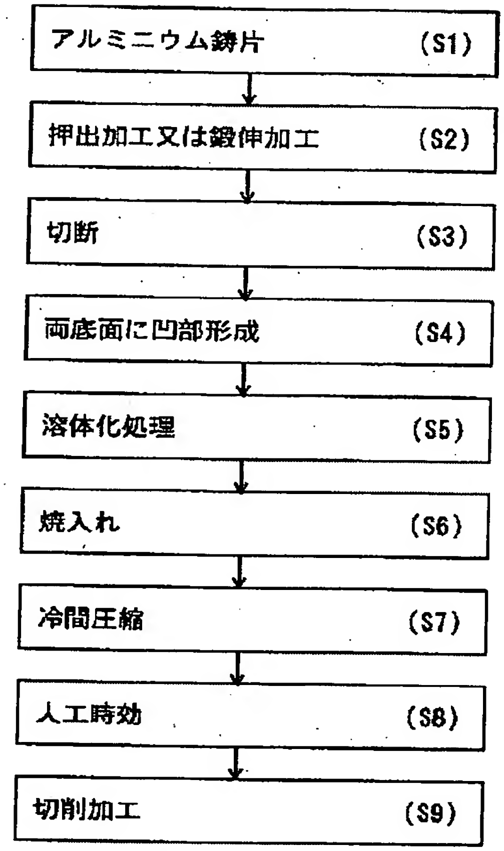
## Patent Abstracts of Japan

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TITLE : METHOD FOR PRODUCING ROTOR MATERIAL MADE OF ALUMINUM ALLOY

ABSTRACT : PROBLEM TO BE SOLVED: To provide a method for producing a rotor material made of an aluminum alloy by which its residual stress can be reduced by cold compression.

SOLUTION: Recessed parts are formed on both the end faces of a cylindrical stock consisting of an un-heat-treated JIS 2000 series aluminum alloy. Next, the cylindrical stock is subjected to solution treatment and quenching treatment. After the quenching treatment, cold compression treatment is performed at an ordinary temperature with both the end faces of the cylindrical stock as compression faces. After that, artificial aging treatment is performed thereto to produce the rotor material made of an aluminum alloy.

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(57)□Abstract□
□Problem□It is an object of the present invention to provide a method of manufacturing rotors from an aluminum alloy with residual stress reduced due to the use of cold pressing.

□Means for the Solution of the Problem□ According to the present invention, recesses are formed on both end faces of a cylindrical workpiece made from a non-normalized aluminum alloy of a JIS 2000 system, the workpiece is then

subjected to solution treatment, quenching, cold pressing at room temperature with application of pressure forces to both end faces of the cylindrical workpiece, and then to artificial ageing.

□CLAIMS□

□Claim 1□A method of manufacturing a rotor from an aluminum alloy by forming recesses on both end faces of a cylindrical workpiece made from a non-normalized aluminum alloy of a JIS 2000 system, subjecting said workpiece to solution treatment, quenching, cold pressing at room temperature with application of pressure forces to both end faces of the cylindrical workpiece, and then to artificial ageing.

□Claim 2□ The method according to Claim 1, wherein, during said step of cold pressing, a compression ratio in the workpiece height direction is within the range of 1□5□2%.

□Claim 3□ The method according to Claims 1 or 2, wherein said aluminum-alloy rotor is a turbomolecular-pump rotor.

□Detailed Description of the Invention□
□0001□
□Field of the Invention□The present invention related to a method of manufacturing rotors that are made from aluminum alloys and rotate with high speed.

□0002□
□Description of the Prior Art□In the past, rotors of compressors, pumps, and similar machines have been made predominantly from steel. However, as the speeds of rotation of such rotors increase, a demand arose for decrease in the rotors' weight. For example, Japanese Patent Publication (Kokoku H5□47614), Unexamined Patent Application Publication (hereinafter referred to as "Kokai") 2000□254754 describe rotors made from aluminum alloys. The use of aluminum alloys as materials for rotors becomes a standard routine for pumps operating under conditions of high- and super-high vacuum.

□0003□One good example of such applications is a turbomolecular pump. A turbomolecular pump is a vacuum pump operating on a principle that thin-metal blades (rotor blades) rotate with high speed in order to cause movement of molecules of gas with a certain kinetic velocity and that the amount of molecules of gas that pass through the exhaust side is greater than the amount of molecules that pass through the suction side. Since such pumps create static vacuum, they find wide application for generating high or super-high vacuum, e.g., in semiconductor manufacturing equipment.

□0004□ Patent Publication No. 3099475 discloses a turbomolecular-pump rotor of the type that is produced as a single piece by mechanical cutting, while (Kokai) No. H05□106588 discloses a rotor assembly that consists of a preformed blade ring inserted into a rotor body.

□0005□A picture of a single-piece turbomolecular-pump rotor is shown in Fig. 3. A turbomolecular pump 111 consists of stator blades and rotor blades arranged in an alternating order. The rotor blades 104a are made as a single piece with a rotor 104 that has an axle 103. In Fig. 3, the rotor 104 and rotor blades 104a are shown hatched. The rotor 104 can be driven into a high-speed rotation with the use of a high-frequency motor 101, which is installed stationary and is arranged in a mounting recess 115 of the rotor shaft 103. The rotor shaft is supported by a radial magnetic bearing 107 and an axial magnetic bearing 108.

□0006□The rotor 104 rotates in a vacuum of 1 Torr (□101325□760 Pa) or higher with the rotation frequency of 20000□90000 rpm so that kinetic velocity of molecules at the tips of the rotor blades is within the range of 200□1400 m/s. The rotor temperature reaches 100□150 °C.

□0007□For working under such [sever] conditions, irrespective of the type of the turbomolecular pump, the material for the rotor was chosen as JIS 2000-system aluminum alloy that provides low weight, sufficiently high mechanical strength, and high resistance to creeping.

□0008□Manufacturing of a single-piece rotor, such as rotor 104, from an aluminum alloy of the JIS 2000 system involves the following processes.

(Process 1) Cutting off a cylindrical piece of a predetermined length from a round aluminum-alloy workpiece of a predetermined diameter produced by extrusion or cogging.

□0009□(Process 2) Forming a mounting recess 115 (for attachment of the rotor shaft 103) in the obtained cylindrical workpiece, by cutting or die forging. This process is required for shortening time that may be required for machining the rotor 104 on the final manufacturing stage (Process 6) and for improving a coefficient of material utilization.

□0010□Fig. 4 is a view of a workpiece that passed through the (Process 2). Imaginary lines on this drawing show the outlines of the final rotor after machining on the final stage (Process 6). Fig. 4 shows a recess 115 formed in the lower end face of the cylindrical workpiece 116.

□0011□(Process 3) The cylindrical workpiece 116 is subjected to solution treatment at a predetermined temperature and is then subjected to quenching for obtaining mechanical properties required for the rotor 104.

□0012□(Process 4) In order to remove residual stress, the cylindrical workpiece 116, in which the recess 115 has been made, is compressed from both end faces with a predetermined compression ratio (hereinafter, this operation will be called "cold pressing") . Cold pressing of the cylindrical workpiece 116 with the recess 115 may also be carried out by compressing it from the outer peripheral side, but in order to provide a turbomolecular pump of a predetermined exhaust capacity, the diameter of the rotor 104 should remain unchanged and, therefore, if the compression force is applied from the peripheral direction, it is necessary to match the diameter of the rotor 104 with dimensions of various standardized dies. In specific operation (Process 4), the workpiece 116 was compressed from both end faces.

□0013□(Process 5) The cylindrical workpiece 116 is subjected to artificial ageing at a temperature required for obtaining rotor 104 with appropriate mechanical characteristics. As a result, an aluminum-alloy rotor workpiece needed for subsequent processing is produced.

(Process 6) The obtained aluminum-alloy rotor workpiece is machined for forming rotor blades 104a by mechanical cutting and for completing the manufacture of the turbomolecular-pump rotor 104.

□0014□

□Problems to be Solved by the Present Invention□However, mechanical cutting on the stage of (Process 6) generates deformations in the turbomolecular pump rotor workpiece obtained after (Processes 1□5). These deformations may change the rotor to unacceptable dimensions and lead to irreparable damage of the rotor. This is because, in a turbomolecular pump, a stack of rotary blades has each rotary blade inserted between a pair of adjacent stationary blades with a very small gap therebetween, and even a slight variation in the rotor blade dimensions may cause physical contact between the rotary and stationary blades and thus may cause damage.

□0015□The aforementioned deformations in mechanical treatment may result from occurrence of residual stress in the final aluminum-alloy rotor workpiece, which, in turn, may be caused by insufficient removal of residual stress generated by cold pressing of the cylindrical workpiece in (Process 4).

□0016□The authors of the present patent application made an attempt to reduce the residual stress in the aluminum-alloy rotor workpiece by increasing the quenching temperature in (Process 3), irrespective of the cold pressing. It appeared so that the above attempt allowed to some extent decrease the residual stress. However, since JIS 2000-system aluminum alloys are very sensitive to the temperature of quenching, the solution of the first problem lead to a new and more essential problem – it becomes impossible to provide the rotor with an appropriate mechanical strength.

□0017□In their search of new ways for the solution of the problem, besides the aforementioned increase in the temperature of quenching, the authors have found that the residual stress is lower on the end face that has the recess 115 than on the end face that does not have a recess.

□0018□The present invention is based on the aforementioned finding with regard to development of deformations in manufacture of a turbomolecular pump rotor and has for its object to provide a method of manufacturing an aluminum-alloy rotor workpiece which is characterized by a reduced residual stress in a rotor workpiece obtained after cold pressing of a cylindrical body.

□0019□
□Means for the Solution of the Problems□The above problems are solved by the present invention the principle of which is described below. More specifically, the invention provides a method of manufacturing a rotor from an aluminum alloy by forming recesses on both end faces of a cylindrical workpiece made from a non-normalized aluminum alloy of a JIS 2000 system, subjecting said workpiece to solution treatment, quenching, cold pressing at room temperature with application of pressure forces to both end faces of the cylindrical workpiece, and then to artificial ageing.

□0020□The principle of the invention consists in that, in order to reduce a contact area between the end face of the cylindrical workpiece (i.e., the pressure-application surfaces of the workpiece) and the platen of the press used for cold pressing, recesses are formed on both end faces. Provision of the recesses reduces contact friction between the cylindrical workpiece and the aforementioned platen.

□0021□The method of the present invention makes it possible to produce, from a cylindrical body, an aluminum alloy rotor workpiece with residual deformations lower than in the case of a convention method due to the fact that cold pressing facilitates plastic deformation of crystalline grains in the material near the end faces of the workpiece. The aforementioned decrease of the residual stress, in turn, reduces deformations caused by mechanical cutting in the subsequent manufacturing processes and thus allows obtaining of an aluminum-alloy rotor with accurate dimensions. What is meant herein under the term “recess” is a cavity formed on a part of the contact surface (pressure application surface) between the platen of a press and the cylindrical workpiece. What is meant under the term “aluminum alloy rotor workpiece” is a form of the workpiece obtained after the cylindrical workpiece passed through the processes of solution treatment, quenching, cold pressing, and artificial ageing.

□0022□According to the method of Claim 1 of the present invention’s claims, during said step of cold pressing, a compression ratio in the workpiece height direction should be within the range of 1□5□2%. Cold pressing with the

compression ration in the aforementioned range makes it possible to reduce the residual stress without noticeably decreasing the strength of the aluminum alloy rotor workpiece.

□0023□□ According to method of Claims 1 or 2 of the present invention's claims, the aluminum-alloy rotor may comprise a turbomolecular-pump rotor. The residual stress that remains in the aluminum alloy rotor workpiece should be at a level that does not cause deformations. Furthermore, the use of the aforementioned aluminum alloy rotor workpiece free of deformations in the production of a turbomolecular pump rotor makes it possible to obtain a rotor of accurate dimensions.

□0024□

□Description of Practical Embodiments□The invention will be further explained by way of practical examples with reference to the attached drawings. It should be understood that the invention is not limited by these examples and that various modifications are possible.

□0025□Fig. 1 is a flowchart of processes for production of a turbomolecular pump rotor from an aluminum alloy workpiece with the use of a method of the invention. Fig. 2 is a longitudinal sectional view of a cylindrical workpiece used in the manufacture of the turbomolecular pump rotor.

□0026□The explanation will follow the flowchart of production processes shown in Fig. 1.

(1) First, an aluminum alloy ingot (billet□slab, etc.) is obtained (S1).

(2) An aluminum alloy body of a round cross section is produced from the aforementioned ingot by extrusion, forging, or cogging. In the case of cogging, the ingot is first formed into a rectangular body by free forging and then into a body of a round cross section by swaging and die forging. (S2).

(3) A cylindrical workpiece is produced by cutting off a piece of a predetermined length from the obtained aluminum alloy body of a round cross section.

□0027□(4) A recess 5 is formed by a known die-forming method or mechanical cutting on one end face of the cylindrical workpiece obtained in the process (S3) for forming a rotor shaft accommodation opening (Fig. 2) (S4).

□0028□A sectional view of the cylindrical workpiece with a large recess 5 on one end face and a small recess 3 on the other end face is shown in Fig. 2. In this drawing, the final outlines of the turbomolecular pump rotor 4 and the rotor blades 4a obtained after mechanical cutting are shown by imaginary lines.

□0029□A two-stage formation of the large recesses 5 and the small recess 2 on both end faces of the cylindrical workpiece 1 is carried out not only merely for

saving time that may be required for machining the turbomolecular pump rotor on the last stages, but also for promoting plastic deformation of crystal grains and for reducing residual stress near the end faces of the aluminum alloy rotor workpiece. In the drawing, configuration of the recesses is shown along with the final shape of the rotor drawn by imaginary lines.

□0030□Thus, provision of the recess on both end faces of the cylindrical workpiece 1 effectively reduces residual stress developed in the cylindrical workpiece as a result of the cold pressing. This allows obtaining an aluminum alloy rotor workpiece with reduced residual stress. Solution of the problem associated with residual stress, in turn, makes it possible to obtain the final product, i.e., the turbomolecular pump rotor, with dimensional accuracy within allowable tolerances.

□0031□Although the method of manufacturing an aluminum alloy rotor workpiece by cold pressings cylindrical body 1 made from non-normalized JIS 2000-system alloy and provided with the large recess 5 and the small recess 2 on the pressure-application surfaces was described with regard to the turbomolecular pump rotor 4, it should be understood that the method of the invention is not limited only by the turbomolecular pump rotors, and the same method can be used for obtaining precision aluminum alloy parts for manufacturing rotors of pumps of other types, as well as for rotors of compressors, expanders, or the like.

□0032□Finally, the method of manufacturing an aluminum alloy workpiece having low residual stress after cold-pressing a workpiece with a [noticeable] residual stress on predetermined pressure application surfaces can be carried out if the recesses are formed on the aforementioned predetermined pressure-application surfaces prior to the cold pressing operation and if the subsequent cold pressing is performed with the compression coefficient that falls into a predetermined range.

□0033□A recess area ratio (which is a ratio of the area occupied by the recess to the entire pressure application area of the end face) used in cold pressing will depend on the type of the aluminum alloy and cannot be given as a single recommendation for all possible applications. The value of this ratio should be selected by taking into account deformations that occur in the selected aluminum alloy during compression.

□0034□In accordance with the present embodiment of the invention, each end face of the cylindrical workpiece 1 has one recess (i.e., recess 5 on one side and recess 2 on the other side, respectively). Such an arrangement is determined by the construction of specific turbomolecular pump rotor 4. If necessary, however, several recesses can be formed on each end face, if such an arrangement does not violate precision dimensions of the final product.

□0035□(5) The cylindrical workpiece 1 with the preformed large recess 5 and small recess 2 is heated to a predetermined temperature and is subjected to solution treatment (S5).

(6)Following the solution treatment in the process (S5), the cylindrical workpiece 1 heated to a predetermined temperature is quickly cooled by quenching (S6).

□0036□(7) The cylindrical workpiece 1 quenched in the process (S6) has residual stress accumulated in the preceding operations. In order to reduce this stress, it is subjected to cold pressing at room temperature (S7).

□0037□It is understood that recesses 5 and 4 formed in the aforementioned process (S4) on the pressure-application surfaces of the cylindrical workpiece 1 are preserved after cold pressing. It is recommended to carry our cold pressing with the coefficient of compression within the range of 1□5□2%. This is because a practically meaningful residual stress reduction effect is achieved only if the coefficient of compression exceeds 1.5%. On the other hand, if the aforementioned coefficient exceeds 2%, the effect will be diminished by a decrease of the strength in the ST direction [ST direction means Short Transverse Direction of the workpiece for forging – translator's note].

□0038□In the above embodiment, the residual stress was reduced by subjecting the workpiece to cold pressing with the aforementioned coefficient of compression. The workpiece is then machined in the below-described process (S9) of mechanical cutting for obtaining the turbomolecular-pump rotor. In this case, deformations that may be caused by cutting should be within the limits of allowable dimensional tolerances.

□0039□(8) The cylindrical cold-pressed workpiece 1 is subjected to artificial ageing by being retained for a predetermined time at a predetermined temperature in an artificial ageing apparatus. As a result, an aluminum alloy rotor workpiece acquires appropriate strength (S8).

(9)The aluminum alloy workpiece that passed through the process (S8) is subjected to mechanical cutting and is formed into the turbomolecular pump rotor 4 (S9). Since the turbomolecular pump rotor 4 obtained by the method of the invention has reduced residual stress, it can be manufactured with deformations caused by mechanical cutting within allowable limits. In other words, the rotor is produced with precision dimensions.

□0040□
□Practical Examples□The invention will be further explained in more detail with reference to practical and comparative examples. It is understood, however, that these examples should not be construed as limitative. A turbomolecular pump rotor was manufactured by following the sequential steps described in the subsequent practical examples.

□0041□

□Table 1□

| | Work piece No. | Alloy Designation | Shape | Solution temperature °C | Quenching Medimum | Compression ratio % | Artificial Aging | Residual Stress Kg/mm$^2$ Max | Min | Stra-in |
|---|---|---|---|---|---|---|---|---|---|---|
| Pr. Ex. | 1 | 2014 | H type | 495-505 | Cool water | 1.5-2 | 170-180°C 10 hr | 0.9 | -2.3 | O |
| | 2 | 2618 | | 525-535 | Warm water | 1.5-2 | 195-205°C 20 hr | 1.8 | -0.5 | O |
| Comp. Ex. | 3 | 2014 | Recess type | 495-505 | Cool water | 1.5-2 | 170-180°C 10 hr | 4.15 | -2.3 | X |
| | 4 | 2618 | | 525-535 | Warm water | 1.5-2 | 195-205°C 20 hr | 5.19 | 0.2 | X |

□0042□Types of aluminum alloys, solution treatment temperatures, quenching conditions, cold pressing ratio, and artificial ageing conditions are shown in Table 1. Residual stress was evaluated in cylindrical workpieces also after completion of artificial ageing. Residual stress was measured by a small-hole drilling method according to standard ASTM E 837 with the use of measurement instrument FRS-2-23 (the product of Tokkyo Sokuki Kenkyusho). In Table 1, negative values correspond to stretching stress, and positive values correspond to compression stress.

□0043□Strains also were evaluated in a completed turbomolecular pump rotor after the mechanical cutting stage.

□0044□In Table 1, symbol “O” designates conditions when strains caused by the manufacturing process are within theallowable tolerances, while symbol “X” designates conditions when the strains go beyond the allowable limits.

□0045□(Practical Examples) These examples relate to workpiece samples which in Table 1 are designated as No. 1 and No. 2. Samples No. 1 and 2 are taken from aluminum alloy rotor workpieces produced with recesses made in the cylindrical bodies prior to solution treatment. The shapes of cylindrical bodies corresponding to Samples No. 1 and 2 are shown in Fig. 2.

□0046□In Fig. 2 points in which residual stress was measured are shown by letter “A”. It can be seen from Table 1 that Samples No. 1 and 2 have significantly lower residual stress than the comparative samples. In these samples, the strains caused in the turbomolecular rotor by mechanical cutting are also within the allowable limits. Such decrease in the residual stress and the

resulting minimization of the strains cause by manufacturing processes were achieved due to cold pressing of the aluminum workpiece, having recesses on both end faces, with a predetermined compression ratio.

□0047□(Comparative Examples) These examples relate to workpiece samples which in Table 1 are designated as No. 3 and No. 4. The turbomolecular pump rotors from which these sample were take were produced by the same method as described above, with the exception that, prior to solution treatment ,a recess was formed only one end face of the workpiece. The shapes of cylindrical bodies corresponding to Samples No. 3 and 4 are shown in Fig. 4.

□0048□In Fig. 4, point in which residual stress was measured on the end face without the recess is shown by letter "A'".

□0049□In Samples 3, 4, strains generated in the material after mechanical cutting exceed the allowable tolerances. This results from the fact that, prior to cold pressing, the recess was formed only on one end face, and therefore it was impossible to provide sufficient reduction of residual stress in the vicinity of the end face that did not have the recess.

□0050□
□Effects of the Invention□The effects produces by the present invention are described below.

(1) Cold pressing of a cylindrical workpiece (made from non-normalized JIS 2000 system aluminum alloy) with application of force from both end faces that have been provided with preformed recesses reduces contact friction between the cold-press platen and the pressure-application surface. This promotes plastic deformations of crystal grains in the vicinity of the pressure-application surfaces, and thus reduces residual deformations in the workpiece. Since the workpiece obtained by the above method has reduced residual stress, the rotor obtained by machining the above workpiece is produced with high dimensional accuracy. (Patent Claim 1)

□0051□(2) Cold pressing with compression coefficient of 1.5 to 2% promotes plastic deformation of crystal grains without scarifies of mechanical strength of the workpiece material. Therefore, the decrease in residual stress is achieved along with sufficient endurance in the workpiece material. (Patent Claim 2).

□0052□(3) The aforementioned method of manufacturing aluminum alloy rotor workpieces makes it possible to produce turbomolecular pump rotors of excellent dimensional accuracy and at the same time to increase production yield in the manufacture of such rotors. (Claim 3).

□Brief explanation of the Drawings□

Fig. 1 is a flowchart of processes for production of a turbomolecular pump rotor.
Fig. 2 is a longitudinal sectional view of a cylindrical workpiece used in the method of the invention.
Fig. 3 is a sectional view of a turbomolecular pump.
Fig. 4 is a sectional view of a conventional cylindrical workpiece.

□Reference Numerals Used in the Description and Drawings□

1 - 116 - cylindrical workpiece
2 - small recess
4 - turbomolecular pump rotor
5, 115 - recesses
101 - high-frequency motor
103 - rotor shaft
104 - rotor
105 - stator blades
107 - radial magnetic bearing
108 - axial magnetic bearing
111 - turbomolecular pump
A, A' – points of residual stress measurement

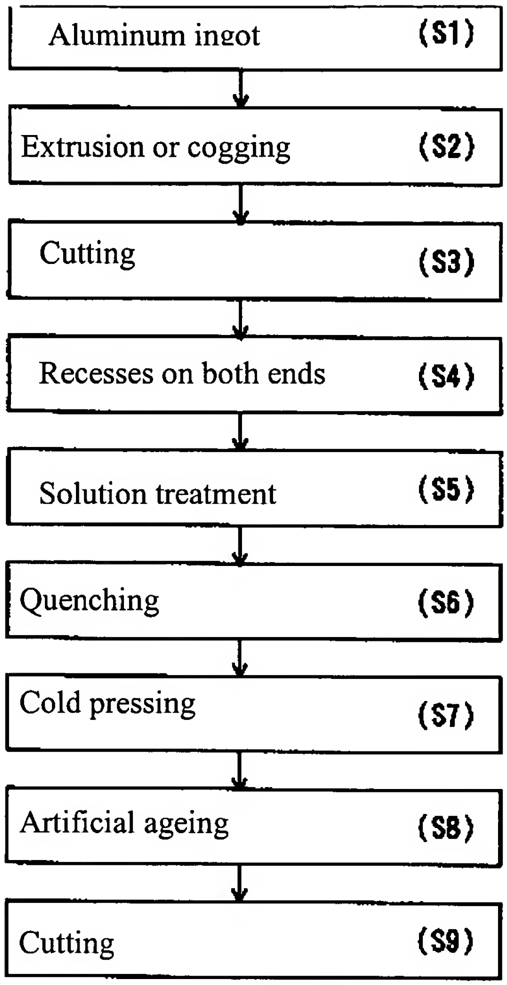
Aluminum ingot (S1)
Extrusion or cogging (S2)
Cutting (S3)
Recesses on both ends (S4)
Solution treatment (S5)
Quenching (S6)
Cold pressing (S7)
Artificial ageing (S8)
Cutting (S9)

Fig. 1

Fig. 2

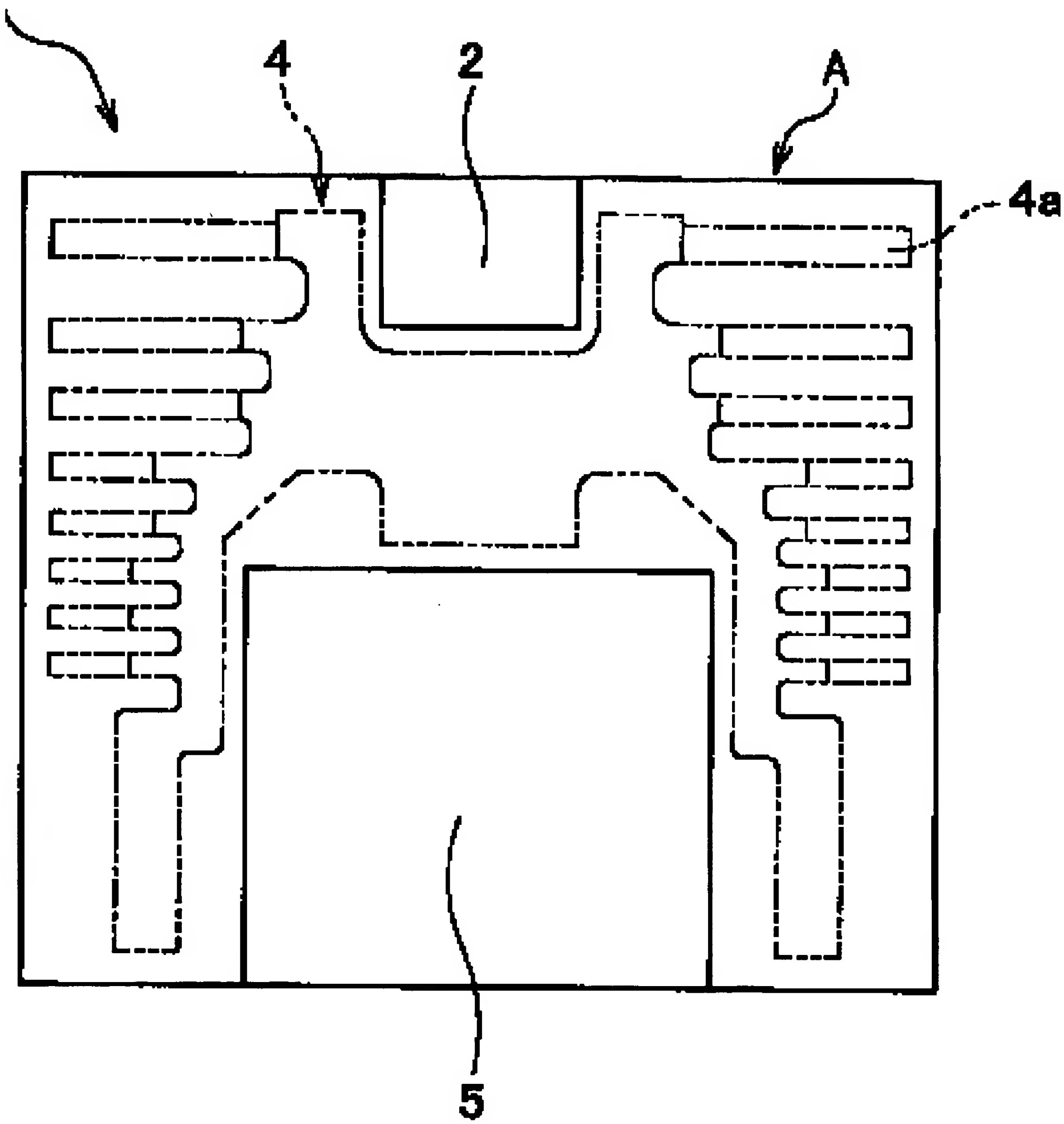

Fig. 3

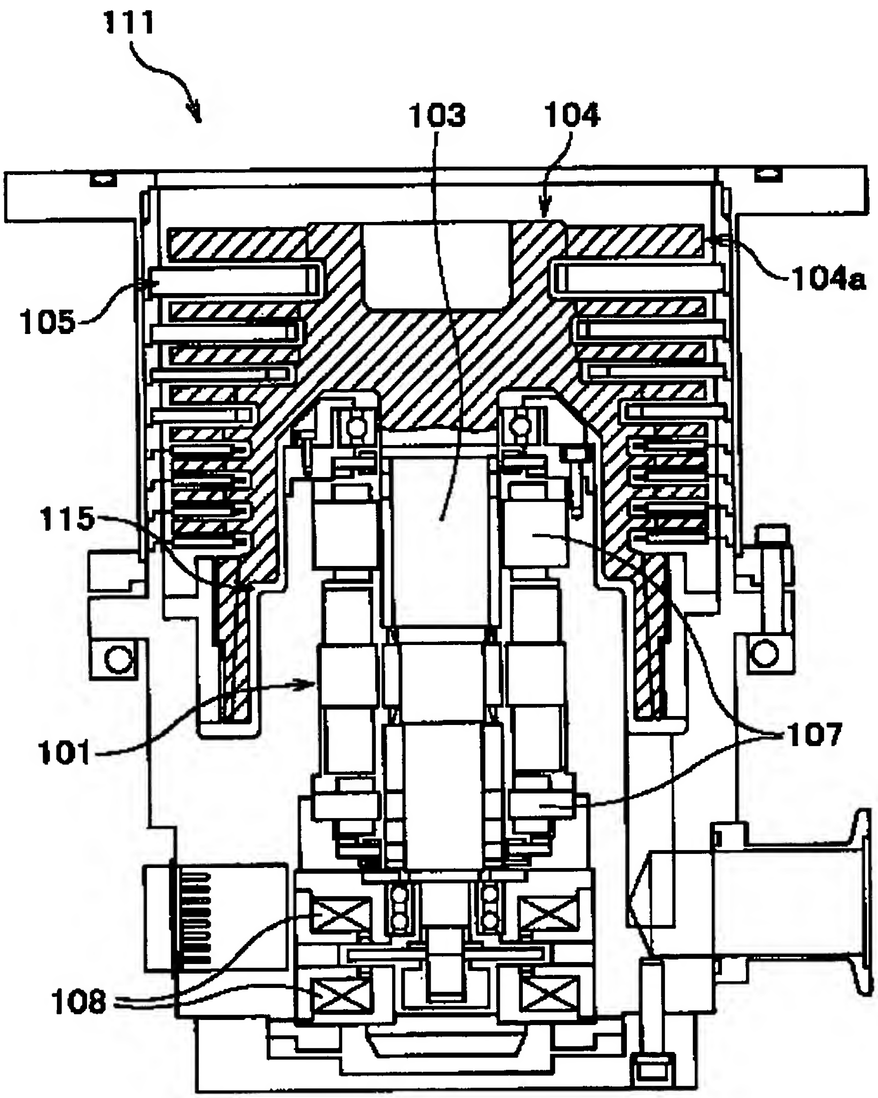

Fig. 4